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T1rho MRI of menisci and cartilage in patients with osteoarthritis at 3T

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ABSTRACT

Objective: To assess and compare subregional and whole T1rho values (median ± interquartile range) of femorotibial cartilage and menisci in patients with doubtful (Kellgren–Lawrence (KL) grade 1) to severe (KL4) osteoarthritis (OA) at 3T.
Materials and methods: 30 subjects with varying degrees of OA (KL1–4, 13 females, 17 males, mean age ± SD = 63.9 ± 13.1 years) were evaluated on a 3T MR scanner using a spin-lock-based 3D GRE sequence for T1rho mapping. Clinical proton density (PD)-weighted fast spin echo (FSE) images in sagittal (without fat saturation), axial, and coronal (fat-saturated) planes were acquired for cartilage and meniscus Whole-organ MR imaging score (WORMS) grading. Wilcoxon rank sum test was performed to determine whether there were any statistically significant differences between subregional and whole T1rho values of femorotibial cartilage and menisci in subjects with doubtful to severe OA.
Results: Lateral (72 ± 10 ms, median ± interquartile range) and medial (65 ± 10 ms) femoral anterior cartilage subregions in moderate–severe OA subjects had significantly higher T1rho values ($P < 0.05$) than cartilage subregions and whole femorotibial cartilage in doubtful–minimal OA subjects. There were statistically significant differences in meniscus T1rho values of the medial posterior subregion of subjects with moderate–severe OA and T1rho values of all subregions and the whole meniscus in subjects with doubtful–minimal OA. When evaluated based on WORMS, statistically significant differences were identified in T1rho values between the lateral femoral anterior cartilage subregion in patients with WORMS5–6 (advanced degeneration) and whole femorotibial cartilage and all cartilage subregions in patients with WORMS0–1 (normal).
Conclusion: T1rho values are higher in specific meniscus and femorotibial cartilage subregions. These findings suggest that regional damage of both femorotibial hyaline cartilage and menisci may be associated with osteoarthritis.

1. Introduction

The earliest biochemical changes that occur in osteoarthritis (OA) are molecular modifications within the cartilage matrix without obvious morphological defects [1,2]. The loss of glycosaminoglycans (GAGs) and breakdown of collagen are typical characteristics of early OA.

The pathogenesis and progression of OA result from diseases not only in articular cartilage, but rather in multiple joint tissues including subchondral bone, synovium, and meniscus etc. Hyaline cartilage and menisci are mainly composed of water, collagen, and proteoglycans (PGs) [3,4]. The menisci play a key role in distributing joint forces, load bearing, and enhancing joint stability within the knee joint. Meniscal tears alter joint biomechanics and correlate with an accelerated progression of cartilage degradation in knee OA compared to OA patients without meniscal tears [5,6].

T1rho (T1Rho or T1ρ – T1 relaxation time in the rotating frame)-weighted MR imaging has recently been proposed as an attractive alternative biomarker to existing conventional morphological MRI methods [2,4,7–10]. T1rho-weighted MR imaging was first described by Redfield [11], and related techniques have been used to investigate the slow motion interactions between macromolecular protons and bulk water [7,9]. T1rho mapping has been shown

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Table 1
Characteristics of the study population.

Patient group and characteristic	Doubtful–minimal OA (KL1–2)	Moderate–severe OA (KL3–4)
All patients		
No. of patients	20	10
Age (years)*	60.3 ± 13.3	71.1 ± 9.6
BMI (kg/m^2)	26.3 ± 4.2	26.9 ± 3.8
Total WORMS**	13.3 ± 12.9	32.5 ± 11.8
Female patients		
No. of patients	9	4
Age (years)	56.7 ± 14.8	74 ± 13
Age range (years)	27–74	58–89
Male patients		
No. of patients	11	6
Age (years)	63.2 ± 11.9	69.2 ± 7.3
Age range (years)	47–80	60–80

Note: WORMS = whole-organ MR imaging score; BMI = body mass index.
* There were significant differences ($P < 0.05$) in total WORMS between doubtful–minimal (KL1–2) and moderate–severe (KL3–4) OA groups.
** There were significant differences ($P < 0.05$) in subjects' age between doubtful–minimal (KL1–2) and moderate–severe (KL3–4) OA groups.

to be sensitive to changes in proteoglycan loss in cartilage [9]. Previous studies have demonstrated that T1rho cartilage values are elevated in OA patients when compared to corresponding healthy subjects [2,7,12]. Other investigators evaluated cartilage degeneration using T2 mapping to compare OA patients with and without meniscal tears [5], and compared the differences in T1rho and T2 values in the menisci in both OA patients with varying degrees of cartilage degeneration and healthy controls [3]. To the best of our knowledge, there have been no studies that perform quantitative analyses and assessments of subregional and global T1rho values of cartilage and menisci in doubtful–minimal (Kellgren–Lawrence grades 1–2) and moderate–severe (Kellgren–Lawrence grades 3–4) OA patients. In this work, at 3T we measured and compared the subregional and global T1rho values of cartilage and menisci in patients with doubtful to severe OA based on both Whole-organ MR imaging score (WORMS) grading and Kellgren–Lawrence (KL) grading. We hypothesized that in OA patients, T1rho values would be increased within specific focal regions of abnormal cartilage and meniscus and not necessarily increased over the entire region of cartilage and meniscus.

2. Materials and methods

2.1. Study population

Thirty subjects ($n = 17$ males and $n = 13$ females, ranging in age from 27 to 89 years, mean $SD = 63.9 \pm 13.1$ years) (Table 1) with normal knees to severe OA based on radiographs [Kellgren–Lawrence (K-L) grading scale 0, 1, 2, 3, and 4 [13,14]] were recruited. The radiographs were read by an experienced (8 years) musculoskeletal radiologist (R.V.) who assigned a KL grade to each knee. The radiographic changes were classified according to the literature as normal (0), doubtful (1), minimal (2), moderate (3) and severe (4) [13,14]. The changes included marginal osteophytes, narrowing of joint space, sclerosis of subchondral bone, and altered bone contours [$n = 7$ as KL1, $n = 13$ as KL2, $n = 6$ as KL3, $n = 4$ as KL4]. The subjects were then further divided into two groups as KL1–2 (doubtful–minimal radiographic changes) and KL3–4 (moderate–severe radiographic changes), respectively. The subjects' body height and weight were obtained in order to calculate the body mass index (BMI). Subjects with a BMI of greater than 24.9 were classified as overweight, and subjects with a BMI of greater than 29.9 were classified as obese [5]. The mean BMI of the subjects included in this study was 26.5 ± 4. The BMI was within the normal range in 11 subjects (37%); 11 subjects were overweight (37%) and 8, obese (26%). There were no significant differences ($P > 0.05$) in BMI between doubtful–minimal (KL1–2) and moderate–severe (KL3–4) OA groups (Table 1). All the subjects provided written informed consent to participate in the study, which was approved by the local institutional review board (IRB).

2.2. Imaging hardware

All MRI experiments were performed on a 3.0T clinical MR scanner (Magnetom Tim Trio, Siemens Medical Solutions, Erlangen, Germany). An 18-cm diameter, 8-channel transmit-receive phased-array knee coil was employed for the imaging measurements.

2.3. Imaging protocol

The morphology of the cartilage and the integrity of the meniscus were assessed by acquiring clinical sagittal proton density (PD)-weighted without fat saturation and axial and coronal PD-weighted fast spin echo (FSE) fat-saturated images for cartilage and meniscus Whole-organ MR imaging score (WORMS) grading.

The parameters for the sagittal PD-weighted without fat saturation sequence were: TR/TE = 3030 ms/19 ms, slice thickness = 2.5 mm, number of slices = 35, number of excitations (NEX) = 1, echo train length = 5, FOV = 100 mm, matrix = 512 × 512, in-plane spatial resolution = 0.19 mm × 0.19 mm, pixel bandwidth = 255 Hz/pixel, echo train length = 5, acquisition time 2 min 4 s.

The parameters for the axial PD-weighted FSE fat-saturated sequence were: TR/TE = 3240 ms/19 ms, slice thickness = 2.5 mm, number of slices = 35, NEX = 1, echo train length = 5, FOV = 100 mm, matrix = 512 × 512, in-plane spatial resolution = 0.19 mm × 0.19 mm, pixel bandwidth = 255 Hz/pixel, echo train length = 5, acquisition time 2 min 4 s.

The parameters for the coronal PD-weighted FSE fat-saturated sequence were: TR/TE = 3240 ms/19 ms, slice thickness = 2.5 mm, number of slices = 35, NEX = 1, echo train length = 5, FOV = 100 mm, matrix = 512 × 512, in-plane spatial resolution = 0.19 mm × 0.19 mm, pixel bandwidth = 255 Hz/pixel, echo train length = 5, acquisition time 2 min 5 s.

For 3D-T1rho Imaging, 3D T1rho-weighted images with parallel imaging (AF = 2) were acquired using the GRE sequence based on the spin-lock technique [2]. The scanning parameters were as follows: duration of each 90° pulse = 200 μs, amplitude of the spin-lock pulse = 250 Hz. TR/TE = 175 ms/2.04 ms, spin-lock frequency = 300 Hz, number of slices = 30, time of spin-lock (TSL) = 2/10/20/30 ms, slice thickness = 3 mm, matrix = 256 × 128, FOV = 15 cm, flip angle = 25°, bandwidth = 260 Hz/pixel, acquisition time 5 min 58 s for each TSL.

3. MR images analysis and processing

The clinical evaluation of cartilage and the menisci was performed using 2D-sagittal PD-weighted FSE without fat saturation and axial and coronal PD-weighted FSE with fat saturation by an experienced (8 years) musculoskeletal radiologist (by _ _). The radiologist was blinded to subjects' specific information, K-L scores, and T1rho relaxation data. Meniscal scoring was performed using the WORMS grading as defined in [5,15]: grade 0, normal meniscus; grade 1, increased signal, no tear; grade 2, small radial tear; grade 3, single tear; grade 4: complex tear; grade 5, displaced tear; grade 6, macerated meniscus. Cartilage scoring was performed using the WORMS grading as defined in [15]: 0 = normal thickness and signal; 1 = normal thickness but increased signal; 2.0 = partial thickness focal defect <1 cm in greatest width; 2.5 = full thickness focal defect <1 cm in greatest width; 3 = multiple areas of partial